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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

**FINAL EXAMINATION
SEMESTER II
SESSION 2013/2014**

COURSE NAME : SEPARATION ENGINEERING
TECHNOLOGY
COURSE CODE : BNQ 20803
PROGRAMME : 2 BNN
EXAMINATION DATE : JUNE 2014
DURATION : 3 HOURS
INSTRUCTION : ANSWER **FOUR (4)** QUESTIONS
ONLY

THIS QUESTION PAPER CONSISTS OF **FOURTEEN (14)** PAGES

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- Q1**
- (a) (i) Define the distillation process. (2 marks)
- (ii) Sketch the distillation equipment with the process that occurs in distillation column. (4 marks)
- (iii) Define and sketch the azeotropic phenomena in distillation column. (4 marks)
- (b) (i) Draw and label the forward-feed multiple-effect and backward-feed multiple-effect evaporator diagram. (4 marks)
- (ii) Describe the process for each type of evaporator. (6 marks)
- (c) Explain briefly about liquid-liquid extraction. (5 marks)

Q2 A liquid feed to a distillation tower at 405.3 kPa abs is fed to a distillation tower. The composition in mole fractions are as follows: n-butane ($x_A=0.4$), n-pentane ($x_B=0.25$), n-hexane ($x_C=0.2$) and n-heptane ($x_D=0.15$). Refer **FIGURE Q2** for the K value.

- (a) Calculate the boiling point and composition of vapor in equilibrium. (The assumption should start from 60 °C and above). (13 marks)
- (b) Calculate the dew point and composition of liquid in equilibrium. (The assumption should start from 100 °C and above). (12 marks)

- Q3** In order to concentrate 4536 kg/h of NaOH solution containing 10 wt% NaOH to a 20 wt% solution, a single-effect evaporator is being used, with an area of 37.6 m². The feed enters at 21.1 °C. Saturated steam at 110 °C is used for heating and the pressure in the vapor space of the evaporator is 51.7 kPa.
- (a) Construct the process flow diagram and label the process variables.
(5 marks)
- (b) Calculate the amount of steam used and the overall heat-transfer coefficient based on the information given in **FIGURE Q3 b (i), (ii) and (iii)**.
(20 marks)
- Q4** Pure isopropyl ether of 450 kg/h is being used to extract an aqueous solution of 150 kg/h with 30 wt% acetic acid by countercurrent multistage extraction. The exit acid concentration in the aqueous phase is 4 wt%.
- (a) Calculate the amounts and compositions of the extract and raffinate phases
(12 marks)
- (b) Calculate the number of stages required based on the liquid-liquid extraction based on the phase diagram in **FIGURE Q4 (b)**.
(13 marks)

- Q5** A tray tower is to be used to remove 99% of the ammonia from an entering air stream containing 6 mol % ammonia at 293 K and 1.013×10^5 Pa. The entering pure water flow rate is $188 \text{ kg H}_2\text{O/h.m}^2$ and the inert air flow is 128 kg air/h.m^2 . Use the equilibrium data as shown in the following **TABLE Q5**. (M_w : air = 29 kg/kmol, water = 18 kg/kmol).

TABLE Q5

Mol fraction of Ammonia	
x_A	y_A
0	0
0.0208	0.0158
0.0258	0.0197
0.0309	0.0239
0.0405	0.0328
0.0503	0.0416
0.0737	0.0657
0.096	0.0915

- (a) Calculate the outlet composition of the gas. (10 marks)
- (b) Plot the operating line and determine the number of theoretical trays needed. (15 marks)

- END OF QUESTION -

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Unit Conversion**R value**

$$R = 8314.34 \text{ J/kg mol.K} = 8314.34 \text{ m}^3 \cdot \text{Pa/kg mol.K} = 8314.34 \text{ kg m}^2/\text{s}^2 \cdot \text{kg mol.K}$$

$$= 82.057 \times 10^{-3} \text{ m}^3 \cdot \text{atm/kg mol.K}$$

Liquid water properties at 0°C (273.2 K)

$$\text{Density } (\rho) = 999.6 \text{ kg/m}^3$$

$$\text{Heat capacity } (c_p) = 4.229 \text{ kJ/kg. K}$$

Pressure

$$1 \text{ bar} = 1 \times 10^5 \text{ Pa} = 1 \times 10^5 \text{ N/m}^2$$

$$1 \text{ atm} = 760 \text{ mm Hg} = 1.01325 \times 10^5 \text{ Pa} = 1.01325 \times 10^2 \text{ kPa} = 1.01325 \text{ bar}$$

$$1 \text{ mm Hg} = 1.333224 \times 10^2 \text{ N/m}^2 = 0.1333224 \text{ kPa}$$

Temperature

$$\text{K} = ^\circ\text{C} + 273.15$$

$$^\circ\text{F} = 32 + 1.8(^{\circ}\text{C})$$

$$^\circ\text{R} = ^\circ\text{F} + 459.67$$

$$100 ^\circ\text{C} = 212 ^\circ\text{F} + 373.15 \text{ K} = 671.67 ^\circ\text{R}$$

$$0 ^\circ\text{C} = 32 ^\circ\text{F} = 273.15 \text{ K} = 491.67 ^\circ\text{R}$$

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FORMULA

Raoult's law – for ideal mixture

$$y_A = \frac{p_A}{P} = \frac{P_A}{P} x_A \quad y_B = \frac{p_B}{P} = \frac{P_B}{P} x_B \quad y_C = \frac{p_C}{P} = \frac{P_C}{P} x_C \quad y_D = \frac{p_D}{P} = \frac{P_D}{P} x_D$$

Hydrocarbon system:

$$y_A = K_A x_A \quad y_B = K_B x_B \quad y_C = K_C x_C \quad y_D = K_D x_D$$

where K_A = vapour-liquid equilibrium constant or distribution coefficient

relative volatility, α_i :

$$\alpha_A = \frac{K_A}{K_{\text{ref.}}} \quad \alpha_B = \frac{K_B}{K_{\text{ref.}}} \quad \alpha_C = \frac{K_C}{K_{\text{ref.}}} \quad \alpha_D = \frac{K_D}{K_{\text{ref.}}}$$

Dew point for a vapour mixture of A, B, C and D:

$$x_i = \sum \left(\frac{y_i}{K_i} \right) = \left(\frac{y_i}{K_{\text{ref.}}} \right) \sum \left(\frac{y_i}{\alpha_i} \right) = 1$$

Liquid composition which is in equilibrium with the vapour mixture:

$$x_i = \frac{\frac{y_i}{\alpha_i}}{\sum \left(\frac{y_i}{\alpha_i} \right)}$$

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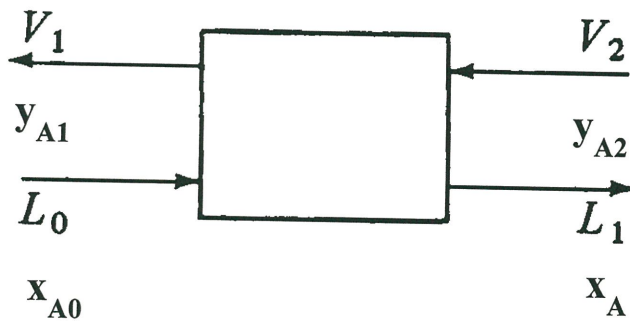
Boiling point for a liquid mixture of A, B, C and D:

$$\sum y_i = \sum K_i x_i = K_{\text{ref}} \sum \alpha_i x_i = 1$$

Vapour composition which is in equilibrium with the liquid mixture:

$$y_i = \frac{\alpha_i x_i}{\sum (\alpha_i x_i)}$$

Single-Stage Extraction



Total material balance:

$$L_0 + V_2 = L_1 + V_1 = M$$

Balance on A:

$$L_0 x_{A0} + V_2 y_{A2} = L_1 x_{A1} + V_1 y_{A1} = M x_{AM}$$

Balance on C:

$$L_0 x_{C0} + V_2 y_{C2} = L_1 x_{C1} + V_1 y_{C1} = M x_{CM}$$

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Absorption:

$$N = \frac{\ln \left[\frac{y_1 - mx_2}{y_2 - mx_2} \left(1 - \frac{1}{A} \right) + \frac{1}{A} \right]}{\ln A}$$

m = slope of equilibrium line (m_2 is used for absorption, m_1 is used for stripping)

A = absorption factor = $A_{av} = \sqrt{(A_1 A_2)}$ $A_1 = L_1 / (m_1 V_1)$

$$A_2 = L_2 / (m_2 V_2)$$

Kremser Equation:

$$N = \frac{\ln \left[\frac{y_{N+1} - mx_0}{y_1 - mx_0} \left(1 - \frac{1}{A} \right) + \frac{1}{A} \right]}{\ln A}$$

m = slope of equilibrium line

A = absorption factor = $A_{av} = \sqrt{(A_1 A_N)}$ $A_1 = L_0 / (mV_1)$ &

$$A_N = L_N / (mV_{N+1})$$

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Balance on A:

$$L' \left(\frac{x_{A0}}{1-x_{A0}} \right) + V' \left(\frac{y_{AN+1}}{1-y_{AN+1}} \right) = L' \left(\frac{x_{AN}}{1-x_{AN}} \right) + V' \left(\frac{y_{A1}}{1-y_{A1}} \right)$$

Evaporation

Total material balance : $F = L + V$

Solute/solid balance: $F(x_F) = L(x_L)$

Energy balance: $Fh_F + S(H_S - h_S) = Lh_L + VH_V$

Heat transfer equation: $q = S\lambda = UA\Delta T = UA(T_S - T_1)$

where $S(H_S - h_S) = S\lambda$

$$h = c_P (T - T_{ref.})$$

$$H_V = \text{latent heat at } T_1 \quad (T_{ref.} = T_1)$$

$$T_1 = T_{sat. at P1} + BPR$$

$$H_V = H_{sat. at P1} + 1.884(BPR)$$

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Figure and Table

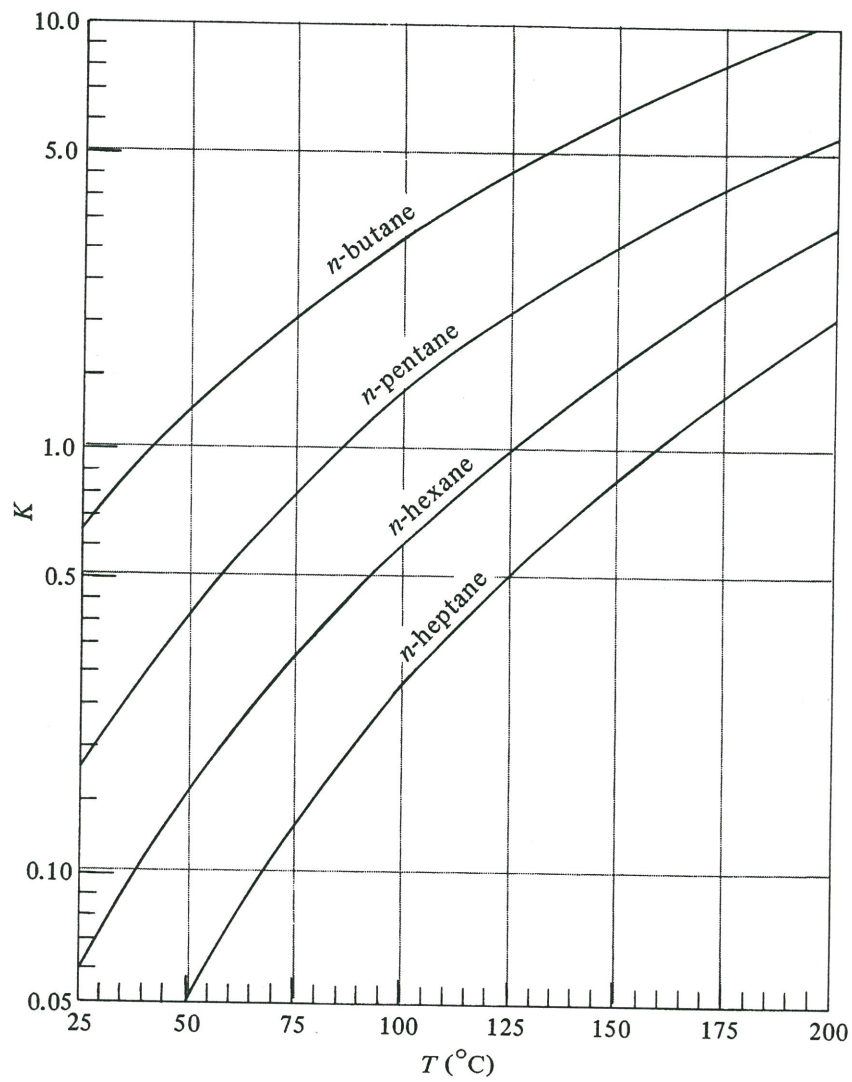


FIGURE Q2

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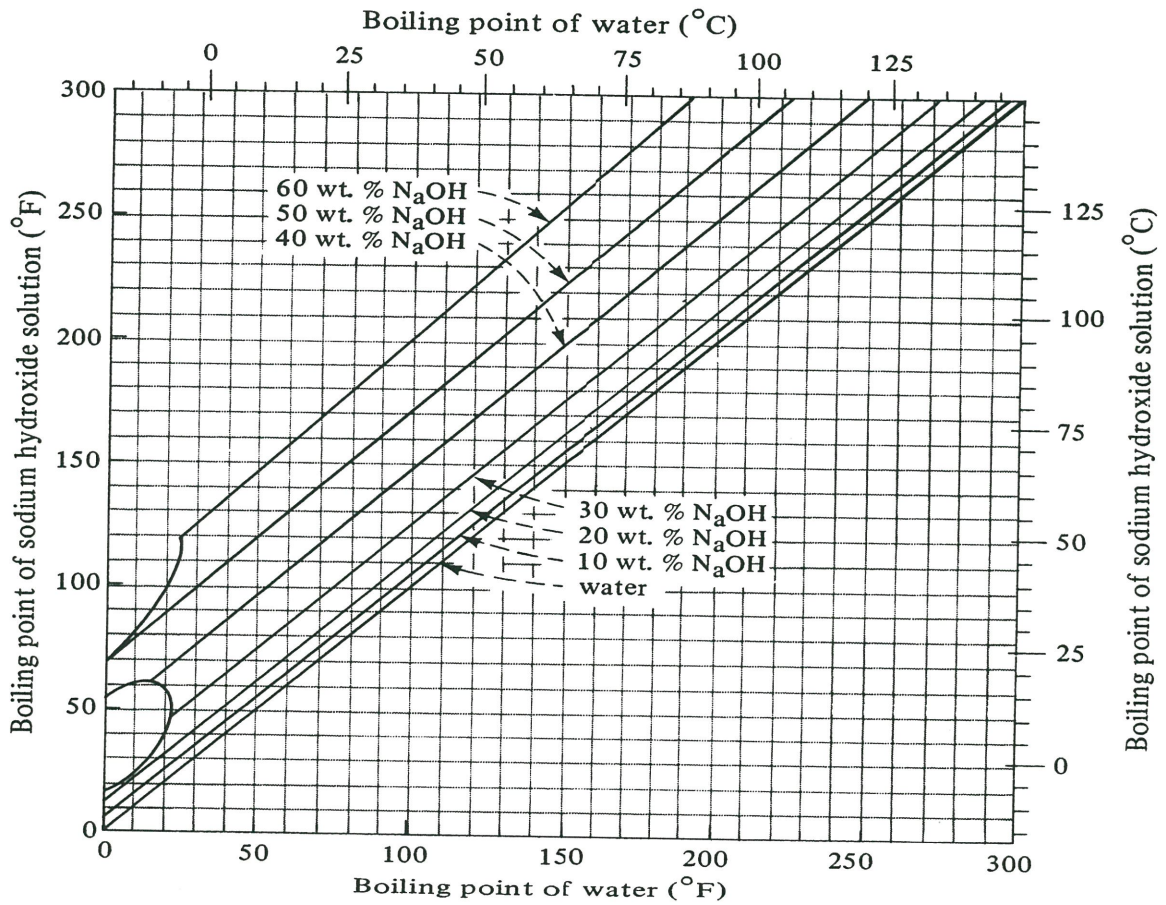


FIGURE Q3 b(i)

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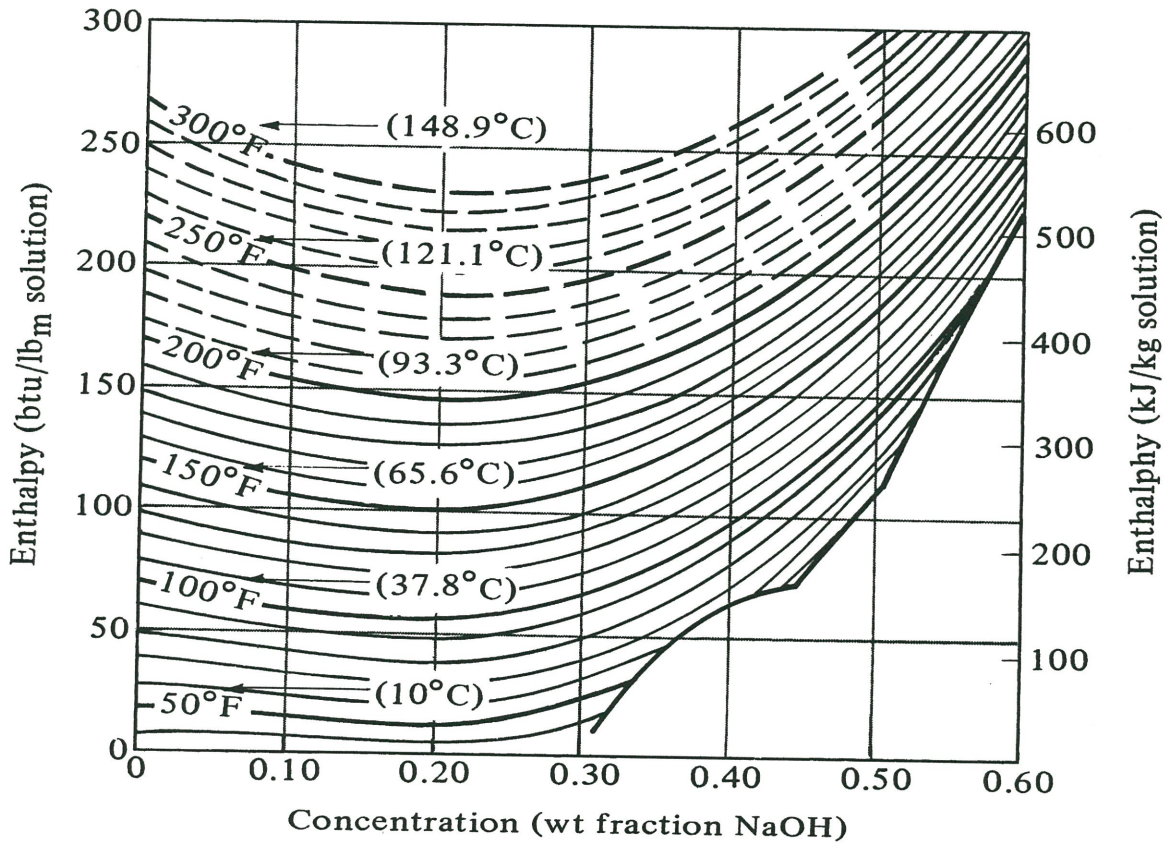


FIGURE Q3 b(ii)

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Properties of saturated steam and water

Temperature (°C)	Vapor Pressure (kPa)	Specific Volume (m ³ /kg)		Enthalpy (kJ/kg)		Entropy (kJ/kg·K)	
		Liquid	Sat'd Vapor	Liquid	Sat'd Vapor	Liquid	Sat'd Vapor
0.01	0.6113	0.0010002	206.136	0.00	2501.4	0.0000	9.1562
3	0.7577	0.0010001	168.132	12.57	2506.9	0.0457	9.0773
6	0.9349	0.0010001	137.734	25.20	2512.4	0.0912	9.0003
9	1.1477	0.0010003	113.386	37.80	2517.9	0.1362	8.9253
12	1.4022	0.0010005	93.784	50.41	2523.4	0.1806	8.8524
15	1.7051	0.0010009	77.926	62.99	2528.9	0.2245	8.7814
18	2.0640	0.0010014	65.038	75.58	2534.4	0.2679	8.7123
21	2.487	0.0010020	54.514	88.14	2539.9	0.3109	8.6450
24	2.985	0.0010027	45.883	100.70	2545.4	0.3534	8.5794
25	3.169	0.0010029	43.360	104.89	2547.2	0.3674	8.5580
27	3.567	0.0010035	38.774	113.25	2550.8	0.3954	8.5156
30	4.246	0.0010043	32.894	125.79	2556.3	0.4369	8.4533
33	5.034	0.0010053	28.011	138.33	2561.7	0.4781	8.3927
36	5.947	0.0010063	23.940	150.86	2567.1	0.5188	8.3336
40	7.384	0.0010078	19.523	167.57	2574.3	0.5725	8.2570
45	9.593	0.0010099	15.258	188.45	2583.2	0.6387	8.1648
50	12.349	0.0010121	12.032	209.33	2592.1	0.7038	8.0763
55	15.758	0.0010146	9.568	230.23	2600.9	0.7679	7.9913
60	19.940	0.0010172	7.671	251.13	2609.6	0.8312	7.9096
65	25.03	0.0010199	6.197	272.06	2618.3	0.8935	7.8310
70	31.19	0.0010228	5.042	292.98	2626.8	0.9549	7.7553
75	38.58	0.0010259	4.131	313.93	2635.3	1.0155	7.6824
80	47.39	0.0010291	3.407	334.91	2643.7	1.0753	7.6122
85	57.83	0.0010325	2.828	355.90	2651.9	1.1343	7.5445
90	70.14	0.0010360	2.361	376.92	2660.1	1.1925	7.4791
95	84.55	0.0010397	1.9819	397.96	2668.1	1.2500	7.4159
100	101.35	0.0010435	1.6729	419.04	2676.1	1.3069	7.3549
105	120.82	0.0010475	1.4194	440.15	2683.8	1.3630	7.2958
110	143.27	0.0010516	1.2102	461.30	2691.5	1.4185	7.2387
115	169.06	0.0010559	1.0366	482.48	2699.0	1.4734	7.1833
120	198.53	0.0010603	0.8919	503.71	2706.3	1.5276	7.1296
125	232.1	0.0010649	0.7706	524.99	2713.5	1.5813	7.0775

FIGURE Q3 b(iii)

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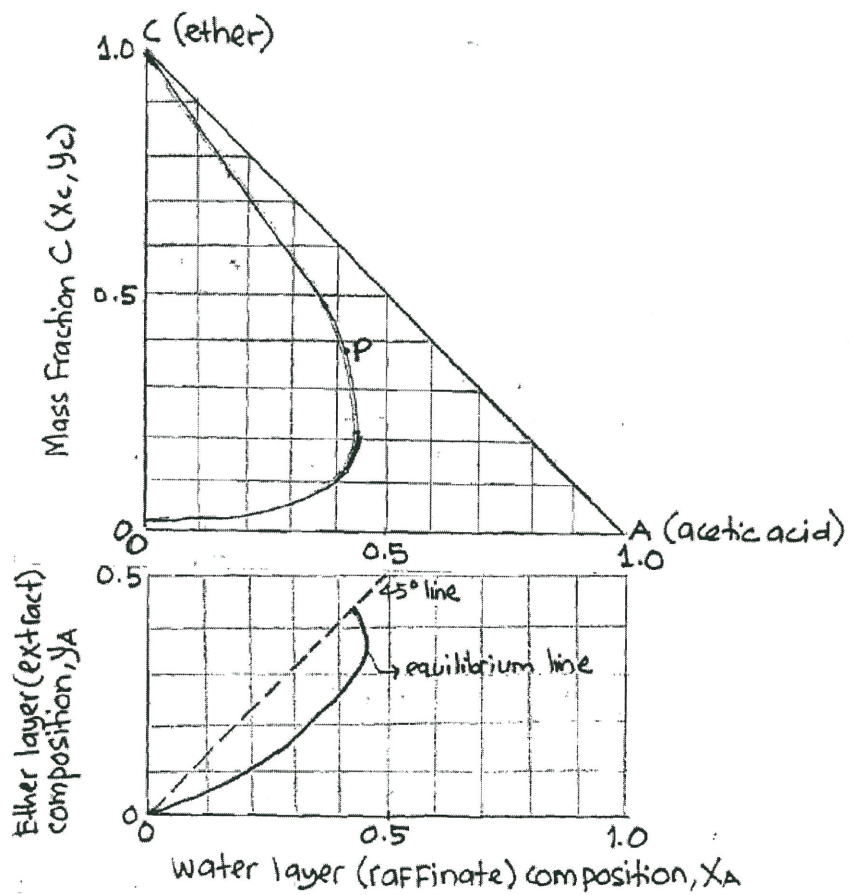


FIGURE Q4 (b)